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A PRESENT VALUE-UNIT COST METHODOLOGY FOR EVALUATING WASTEWATER RECLAMATION AND DIRECT REUSE AT A MILITARY BASE OF OPERATIONS

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Fort Belvoir, Virginia

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The present value method of economic evaluation is applied to a water supply problem typical for a military operation. A relevant unit cost figure, called the "present value-unit cost" (PVUC), is determined and applied to alternative methods for meeting a projected need for water. The concepts of reclamation and dual supply systems are introduced and presented as feasible alternatives. A hierarchy of water use is established, with the highest quality intended for potable purposes. A lesser quality is provided for non-potable uses. A determinant δ x (j),

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which is the difference in the calculated unit costs for the alternatives, is examined over selected planning horizons. It indicates the practicality or impracticality of a particular quality scheme in the comparison of alternatives. A mathematical model is formulated and coded in FORTRAN for use on a digital computer. The calculated δ x (j) is input into the decision and policy making process for selecting an optimal system of water supply for a military base of operations.

The model incorporates the ideas of a dual supply system by the reclamation of treated wastewaters and the direct reuse of these waters after specified advance treatment. The technique used for economic evaluation is the present-value method, by which a direct comparison between alternatives may be made. The results of this study provide to the military logistics planner a methodology by which a least cost alternative may be chosen. In particular, the approach taken provides a framework for evaluation of policy alternatives and for projection in the cost analysis of proposed water supply investment projects.

The model presented focuses on the relationship of a demand for water and alternative methods to satisfy that requirement. The major emphasis is on the role of cost as a determinant, and specifically, the PVUC is used. The model is essentially a difference equation between the calculated PVUC for each alternative taken over selected planning horizons.

The report concludes that:

a. A dual water supply system is a practical alternative to be considered in meeting projected water requirements within a military base of operations.

b. The PVUC is a usable measure by which alternatives may be evaluated. The discriminant δ x (j), which is the calculated difference between the PVUC's of the two alternatives, yields a worthwhile decision variable which can be calculated easily using a digital computer program. When applied over selected planning horizons, the calculated δ x (j) predicts a cost equivalence of the two alternatives at some future point in time.

c. The methodology presented may be applied to existing systems within a military base of operations in conjunction with plans for expansion, or it may be used in the formulation of plans for the creation of new military bases of operation.

PREFACE

The investigation covered in this report was conducted under the authority of Program Element 6.27.08.A; Project 1G762708DJ39, General Support Technology; Task 1G762708DJ39-10, Pollution Abatement.

The work was accomplished by LTC Vincent J. Ciccone, MSC, as part of a continuing study of pollution abatement technology under the general direction of Richard P. Schmitt, Chief, Sanitary Sciences Division, and Kennedy K. Harris, Chief Military Technology Department.

CONTENTS

A PRESENT VALUE-UNIT COST METHODOLOGY FOR EVALUATING WASTEWATER RECLAMATION AND DIRECT REUSE AT A MILITARY BASE OF OPERATIONS

I. INTRODUCTION

1. **Subject.** This report covers a determination of the feasibility of establishing a present value-unit cost (PVUC) methodology for evaluating wastewater reclamation and direct reuse at a military base of operations. The specific objectives are:

a. To present a methodology for evaluating the least cost alternative for meeting projected water supply requirements within a military base of operations.

b. To present the concepts of reclamation and direct reuse of treated wastewaters as an alternative source of supply.

c. To develop a mathematical model which evaluates the alternatives under consideration and serves to produce input into the decision making process. The goal is to give the decision maker quantified data which clearly define the conditions under which reclaiming treated wastewaters for selected uses is both plausible and economically feasible.

2. **Background.** The alternatives available to meet existing and/or projected requirements for water in a military community must include the potential for reclaiming and recycling treated wastewaters.

Under current doctrine, the engineering and chemical research and development agencies within the Army Materiel Command (AMC) in conjunction with the Army Medical Department are responsible for developing and providing water treatment equipment and technology to the units performing water purification in the field. The logistics officer, under advisement by other staff members, determines the total requirement for water. He is responsible on both a short- and long-term basis for the allotment of resources, treatment, storage, and distribution of the available quantities of water. Charged with such responsibilities, these agencies and individuals should have available as much information as possible in order to avoid water shortages, while precluding overcapitalization, and still schedule projects (equipment and policy) that make the best possible use of limited resources.

Hence, with these ideas as background, this paper presents a methodology for determining the least cost plan for the use of alternative sources of water. Its aim is to provide military logistics planners a technique for evaluating the potential for

wastewater renovation and direct reuse. It also suggests the implementation of a dual supply system to meet projected water needs efficiently.

II. INVESTIGATION

3. **Statement of the Problem.** The main problem, as outlined in this paper, is to compare on a PVUC basis alternatives designed to satisfy future water requirements within a military base of operations. The methodology employs a structured mathematical model which simulates a typical water planning situation for such a base.

4. **Approach to the Problem.** The basic considerations involved are:

a. Meet the projected requirement for water over the planning horizon by construction and operation of conventional (i.e., source, treatment, and distribution facilities) supplementing any existing water sources either by importation or new source development.

b. Institute a dual system by recycling treated wastewaters for direct reuse to meet non-potable projected requirements and satisfy potable requirements from existing available (although constrained) sources. The system employs new techniques of advance wastewater treatment and recycles reclaimed wastewaters to satisfy the non-potable users.

The first is designated "Alternative A," and the latter, "Alternative B." A least-cost evaluation model based on the PVUC method of determining cost is pursued for a selected planning horizon, j. A discriminant, which is the PVUC difference between the two alternatives, is evaluated to become the quantified decision discriminant denoting the practicality of selecting a policy of recycling versus one of employing conventional methods.

The strategy used in this approach is: given water requirements, sources, geophysical parameters, and available selected advance wastewater treatment methods, evaluate the alternatives in a total system which permits restoration of treated wastewaters to a desired quality.

The projected water requirements are constraints which must be satisfied. The cost functions, which include capital and operational costs (fixed and variable), are constructed to reflect economies of scale. Optimizing the system (i.e., defining the optimal conditions under which reclamation and direct reuse is advantageous) requires that the relative cost of each alternative for each projected requirement be identified and that the minimum cost solution be selected.

III. RESULTS – MATHEMATICAL DERIVATION OF THE DECISION MODEL

5. **The Model.** The mathematical model is developed as follows:

Term	Definition
$K_j^A = \sum_{i=1}^{k} c_i$	K_j^A = Capital costs of Alternative A i = Process j = Planning horizon period c_i = Cost function
$A_t^A = \sum_{i=1}^{k} a_i$	A_t^A = Operating costs, Alternative A for period t = 1, 2 ––– j
$S_j^A = \sum_{i=1}^{k} s_i$	S_j^A = Salvage value, Alternative A (based on straight line depreciation) S_i = depreciation function
q_t^A	q_t^A = Daily average flow for time period t = 1,2 ––– j Alternative A
X_j^A	X_j^A = PVUC of water in Alternative A
r	r = interest rate
$K_j^B = \sum_{i=1}^{\ell} c_i$	K_j^B = Capital costs, Alternative B Advanced Wastewater Treatment [AWT equipment]
$A_t^B = \sum_{i=1}^{\ell} a_i$	A_t^B = Operating costs, Alternative B [AWT equipment]

$S_j^B = \sum_{i=1}^{\ell} s_i$	S_j^B	= Salvage value, Alternative B (based on straight line depreciation)
q_t^B	q_t^B	= Average daily flow for time period t = 1, 2, ––– j Alternative B
X_j^B	X_j^B	= PVUC of water in Alternative B
$(1 + r)^{-t}$	$(1 + r)^{-t}$	= Discounting factor for present worth calculations
R_j^A	R_j^A	= Discounted present worth annual operating costs Alternative A
R_j^B	R_j^B	= Discounted present worth annual operating costs Alternative B
$b = 0, 1$	b	= On-off multiplier
$\beta = \frac{K_o^B}{K_o^A}$		= Relative capital cost parameter
θ_{1j}, θ_{2j}		= Relative salvage value parameter
δ_{X_j}		= Decision (discriminant which determines whether for any given horizon (j) Alternative A is less or more expensive than Alternative B, dual-recycle system)

a. **Capital Costs.**

Alternative A: $K_j^A = \sum_{i=1}^{k} q_j^A * c_i * b$

Alternative B: $K_j^B = \sum_{i=1}^{\ell} q_j^B * c_i * b$

b. **Operating Costs.**

Alternative A: $A_t^A = \sum_{i=1}^{k} q_t^A * a_i * b$

Alternative B: $A_t^B = \sum_{i=1}^{\ell} q_t^B * a_i * b$

c. **Unit Costs.**

C_t = total cost in any one time period, t.

$C_t = K_t + A_t - S_t$

For Alternative A

$$C_t^A = K_t^A + A_t^A - S_t^A$$

The present value of all costs of the project is obtained by discounting cost in each time period by the cost of capital and summing over the planning horizon. The PVUC is then obtained by dividing through by the sum of the discounted quantities.

Since X_p^A = unknown PVUC of water, assumed to be constant over the planning horizon, and q_t^A = quantity of water produced in time period t, then total cost for water in t is equal to $X_p^A \cdot q_t^A$.

It then follows that for a project with a life of j time units, the sum of the present value costs will be equal to the sum of the quantities produced in each time period multiplied by the PVUC and discounted by the appropriate factor.

Symbolically:

$$\sum_{t=0}^{j} PVC_t^A = \sum_{t=0}^{j} (X_p^A \cdot q_t^A)\ (1+r)^{-t}$$

Since X_p^A is assumed to be a constant it may be factored out of the summation, and upon dividing both sides by the sum of the discounted quantities we have:

$$X_p^A = \frac{\sum_{t=0}^{j} PVC_t^A}{\sum_{t=0}^{j} q_t^A\,(1+r)^{-t}} \qquad \text{(Symbolically)}$$

d. **General Model.**

Let $X_j^A = X_p^A$ where j represents the planning horizon being considered.

Then:

$$X_j^A = \frac{\sum_{t=0}^{j} [K_t^A + A_t^A - S_t^A]\ [(1+r)^{-t}]}{\sum_{t=0}^{j} q_t^A\ (1+r)^{-t}}$$

Since K_t^A is not discounted, it is an immediate cash outlay.[1 2 3]

$$X_j^A \quad \frac{K_j^A + \sum_{t=0}^{j} \frac{A_t^A}{(1+r)^t} - \frac{S_j^A}{(1+r)^j}}{\sum_{t=0}^{j} q_t^A\ (1+r)^{-t}}$$

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1 Jack Hirshleifer, *et al*, *Water Supply Economics, Technology and Policy*, Chicago, The University of Chicago Press, 1966.

2 Larry H. Falk and W. J. Stober, "The Measurement and Comparison of Costs for Alternative Water Replacement Projects," Louisiana State University, Water Resources Research Institute, 1966.

3 A. Maass, *et al*, *Design of Water Resource Systems*, Cambridge, Massachusetts, Harvard University Press, 1962.

(where S_j^A is the salvage value at the end of the planning period, j) which is the average PVUC.

Similarly, for Alternative B:

$$X_j^B = \frac{K_j^B + \sum_{t=0}^{j} \frac{A_j^B}{(1+r)^t} - \frac{S_j^B}{(1+r)^j}}{\sum_{t=0}^{j} q_t^B (1+r)^{-t}}$$

We can now define the differential ΔX_j:

$$\Delta X_j = X_j^A - X_j^B$$

Also let $K_o^A = K_j^A$

$$K_o^B = K_j^B$$

then $\Delta X_j =$

$$\left[\frac{K_o^A + \sum_{t=0}^{j} \frac{A_t^A}{(1+r)^t} - \frac{S_j^A}{(1+r)^j}}{\sum_{t=0}^{j} q_t^A (1+r)^{-t}} \right] - \left[\frac{K_o^B + \sum^{j} \frac{A_t^B}{(1+r)^t} - \frac{S_j^B}{(1+r)^j}}{\sum_{t=0}^{j} q_t^B (1+r)^{-t}} \right]$$

Now after manipulation and simplification and letting

$$\beta = \frac{K_o^B}{K_o^A}$$

$$\alpha = \frac{\sum_{t=0}^{j} q_t^A (1+r)^{-t}}{\sum_{t=0}^{j} q_t^B (1+r)^{-t}} = \frac{\sum_{t=0}^{j} q_t^A}{\sum_{t=0}^{j} q_t^B}$$

$$\theta_{1j} = \frac{S_j^A}{K_o^A\ (1+r)^j}$$

$$\theta_{2j} = \frac{S_j^B}{K_o^B\ (1+r)^j}$$

and

$$R_j^A = \sum_{t=0}^{j} \frac{A_t^A}{K_o^A\ (1+r)^t}$$

$$R_j^B = \sum_{t=0}^{j} \frac{A_t^B}{K_o^A\ (1+r)^t}$$

and the above general expression can be reduced to:

$$\delta X_j = 1 + R_j^A - \theta_{1j} - \alpha\,(\beta + R_j^B - \theta_{2j})$$

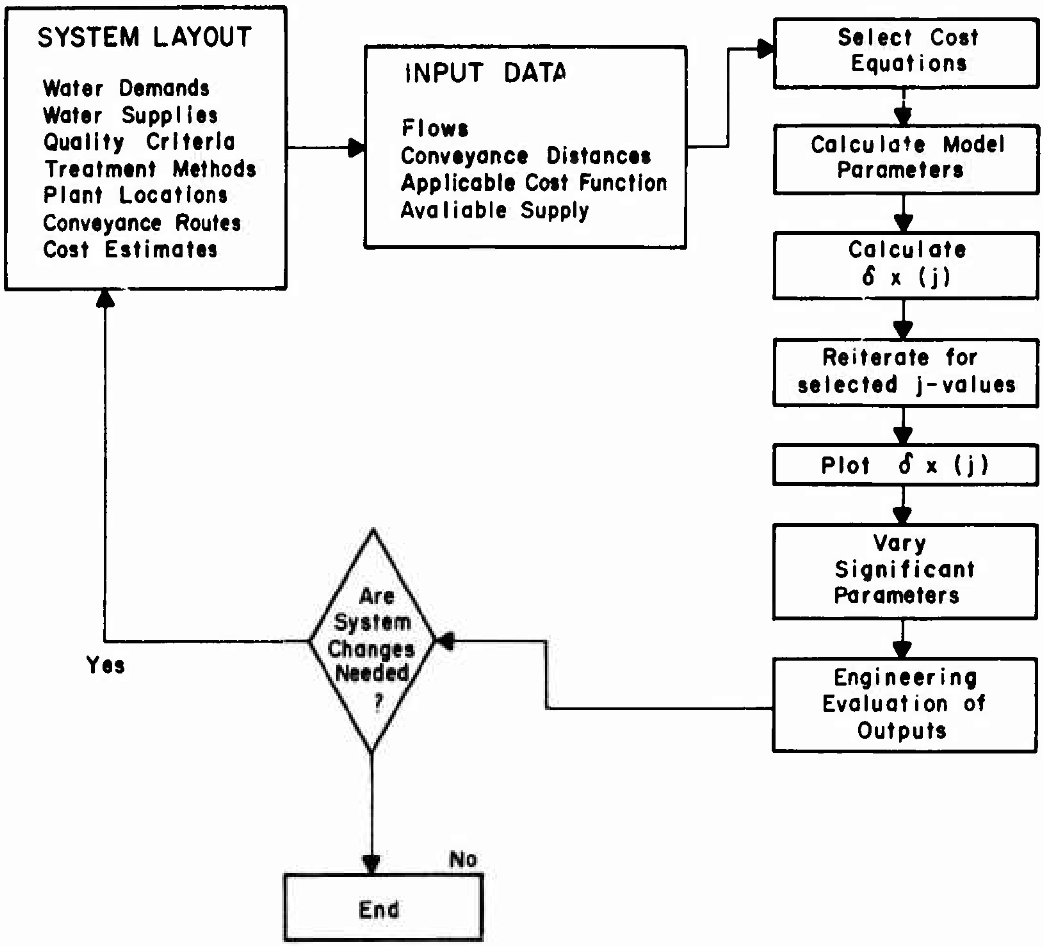
the decision model for planning horizon, j.

If δX_j = (+) Alternative B is preferred,

δX_j = (-) Alternative B is not preferred.

6. **Application.** The methodology developed above is of a general nature. Application requires specification of necessary initial system parameters. The initial state of the system, here a simulated military base of operations, must be specified and defined. A generalized flow diagram of the system and model is presented in the figure (page 9). It illustrates the basic system model components and their respective functional uses. Planning judgment is given a prominent role in this model, especially in defining the initial conditions and for determining any system changes. By allowing such flexibility, the model is raised from being purely hypothetical to being both realistic and applicable.

It is appropriate at this point to mention the relationship between the derived mathematical model and the physical aspects of the military base operation under



Generalized flow diagram of decision model.

consideration. The major components involved which define the scope of the study problem are described in terms of population and flow projections, locations of major facilities, and quality criteria. Before the decision model can be applied, pertinent data defining the following items must be secured in order to structure the model so that it represents the area being studied:

a. Population estimates for the period being considered.

b. Water requirements in terms of quantit , quality, and location.

c. Wastewater flows in terms of quantity, quality, location, and availability.

d. Water supplies in terms of type of source, quality, and availability.

e. Location of existing and proposed facilities.

f. Unit cost information for each process in the model.

g. Quality criteria and treatment requirements.

Detailed background information for each of these items must be available to the planner in order to apply the model. The various sources which may be called upon for this data usually require detailed study of existing engineering reports, strategic and tactical operational plans, site visits, discussion, and correlation with other controlling agencies.

Thus with the primary elements of the problem outlined, the fundamental task is to evaluate the least cost alternative to supply the indicated water requirements.

Input data to the subroutine MODEL is prepared in the form of a two-dimensional matrix (projected water requirements) stating the quantity, the time unit within the planning horizon, and the category of use. The geophysical parameters defining the water supply distribution system, the discount rate, the quant ty of water available, and the desired quality of renovated wastewater are also treated as input data and so specified in the computer program.

A typical simulation run consists of input data specification, execution of the computer program, and analysis of the printed output. The discriminant δ x (j), which indicates the economic practicality of a particular wastewater renovation scheme when compared to the conventional method of water supply, is examined for both algebraic sign and magnitude. The sign is an immediate indicator, while the magnitude

is a measure of the difference between the PVUC's of the two alternatives.

IV. DISCUSSION

7. **Analysis of Methodology.** The planning, design, and implementation of an efficient supply system for a military base of operations are not simple tasks. They involve strategic (policy) as well as operational decisions which are aimed at maximizing the benefits derived from the system while attempting to minimize its costs. Current water and wastewater treatment technology makes it possible to achieve virtually any specified water quality desired. However, economics places a limit upon the water quality usually demanded. A balance or tradeoff between quality desired and the cost of achieving that standard must be considered in the final decision. The concepts of a hierarchy of use and dual supply systems seem to provide a firm basis upon which the balance may rest.

In this methodology, an attempt has been made to find a framework of analysis which will allow the simultaneous evaluation of many alternatives, each designed to satisfy the requirements while accounting for such prominent aspects as health, aesthetics, and costs. It is one which will provide an understanding of a practical least cost alternative and which forms a reasonable basis for input into the decision and policy making process. With such data as input, the making of policies and programs regarding the best use of water resources at a military base of operations is enhanced.

This investigation has resulted in the development of a computerized methodology which uses PVUC theory and digital simulation as a basis for analyzing a complex water supply program. The application of the methodology enables one to compare, on the basis of unit cost, a myriad of feasible alternatives, each designed to satisfy the water requirements within a military base of operations.

From the feasible alternatives, derived by consideration of present and future inputs, efficient, practical least cost solutions may be obtained. Analysis of these solutions yields quantified data available in a simple form to the decision maker(s). This allows decisions to be made with a degree of confidence that they are soundly based and should not be obsolete before their full implementation.

The use of a simulation model as presented in this paper permits the decision maker or planner to focus on key input factors to which the model yields significant quantified responses or outputs. In the total analysis, these key factors and their respective responses require constant review and updating in order to make them meaningful in the final decision.

V. CONCLUSIONS

8. Conclusions. It is concluded that:

a. A dual water supply system is a practical alternative to be considered in meeting projected water requirements within a military base of operations.

b. The PVUC is a usable measure by which alternatives may be evaluated. The discriminant δ x (j), which is the calculated difference between the PVUC's of the two alternatives, yields a worthwhile decision variable which can be calculated easily using a digital computer program. When applied over selected planning horizons, the calculated δ x (j) predicts a cost equivalence of the two alternatives at some future point in time.

c. The methodology presented may be applied to existing systems within a military base of operations in conjunction with plans for expansion, or it may be used in the formulation of plans for the creation of new military bases of operations.

BIBLIOGRAPHY

Berger, Bernard B. "Public Health Aspects of Water Reuse for Potable Supply," Journal American Water Works Association, Vol. 52, No. 5. 1960, pp. 559-606.

Bishop, Bruce, *et al* "Water Reuse Systems Analysis," Journal of Sanitary Engineering Division, American Society of Civil Engineers, Vol. 7, No. 2. 1971, pp. 41-57.

De Vries, Richard N., and Calvin G. Clyde. "Optimization in Municipal Water Supply System Design," Water Resources Bulletin, Vol. 7, No. 5. 1971, pp. 1048-1058.

Dorfman, Robert. "Forman Models in the Design of Water Resource Systems," Water Resources Research, Vol. 1. No. 3. 1965, pp. 329-336.

Falk, Larry H., and W. J. Stober. "The Measurement and Comparison of Costs for Alternative Water Replacement Projects." Louisiana State University, Water Resources Research Institute, 1966.

Grant, E. L., and W. G. Ireson. *Principles of Engineering Economty*, New York, Ronald Press Company, 1964.

Hall, Warren A., and John A. Dracup. *Water Resources Systems Engineering.* New York, McGraw-Hill, 1970.

Haney, Paul D. "Dual Water Systems," Journal American Water Works Association, Vol. 57, No. 9. 1965, pp. 1073-1098.

Haney, Paul D. "Water Reuse of Public Supply," Journal American Water Works Association, Vol. 61, No. 2. 1969, pp. 73-78.

Hirshleifer, Jack, *et al. Water Supply Economics, Technology and Policy.* Chicago, The University of Chicago Press, 1966.

Maass, A., *et al. Design of Water Resource Systems.* Cambridge, Massachusetts, Harvard University Press, 1962.

Metzler, Dwight F., and Heinz B. Russelmann. "Wastewater Reclamation as a Water Resource," Journal American Water Works Association, Vol. 60, No. 1. 1968, pp. 95-102.